Application:
- ☒ DESIGN
- ☒ CONSULTANT ENGINEERING
- HYDRAULICS
- ☒ ENGINEERING SUPPORT
- ADMINISTRATION
- OTHER

Directive: The following guidelines establish the design procedures for selecting vertical alignment.

Alignment. Of all the various elements to consider when designing a new highway, the selections of the horizontal and vertical alignments are of greatest importance in establishing the character of the highway. Alignment affects the operating speeds, sight distance capacity, and has a significant impact on safety operations of the highway. Once the line and grade are established, rarely can we afford to return and make significant improvements.

Vertical Alignment. Vertical alignment, defined as a mix of tangent gradients and vertical (parabolic) curves, is also referred to as the profile grade line (PGL)

General Controls. The characteristics of vertical alignment are greatly influenced by type of terrain, design speed and roadway classification. Additional factors impacting the vertical alignment of a highway are locations of utilities, location of existing major intersecting roadways, bridge structures, earthwork balance and coordination with horizontal alignment, etc. Within these controls, several general factors must be considered.

1. A smooth gradeline with gradual changes, consistent with the type of highway and the character of the terrain.

2. Avoid numerous breaks and short length grades.

3. Avoid placing a low point of a sag vertical curve in cut sections. To drain these low points, additional construction cost may be incurred.

4. Short humps in vertical alignment, that tend to drop out of sight, shall be avoided whether on a horizontal curve or a tangent alignment.

5. Maintain moderate grades through intersections to facilitate turning movements.

6. Consider auxiliary lanes where passing opportunities are limited and it is possible that the capacity may be jeopardized by slow moving trucks or other vehicles either ascending or descending.

7. On four-legged, at-grade intersecting roadways, the profile "through the intersection" (both left and right of the mainline) shall be reviewed as one continuous vertical alignment.

Maximum Grades. Maximum grades are based upon the functional classification of the highway, terrain over which the highway traverses and the Design Speed. (Refer to Table VA-1). The maximum grades shown shall be used only where absolutely necessary rather than as a value to be used in most cases. Grades much flatter than maximum normally shall be used.

Minimum Grades. Minimum grades are generally a function of adequate drainage. On roadways, a minimum grade of 0.5 percent is desired. Use of flatter grades may be justified under extenuating circumstances only.

Minimum Ditch Grades. Roadside and median ditches may require grades steeper than the profile grade of the roadway to adequately handle drainage. Special attention shall be directed to minimum ditch grades. Any ponding of water in roadway ditches, particularly on soils which become unstable when wet, can have a detrimental effect on the subgrade. Ditch gradients shall not be less than 0.5 percent and preferably steeper. Refer to Chapter 3, "Open Drainage," of the Highway Drainage Manual for additional control for ditches (I-3-A-1).

Critical Length of Grade. The steepness of the grade is not the only control when considering vehicle operating characteristics. The length of the grade may become a critical factor and shall be considered.

When passing opportunities are limited, long lines of vehicles queue behind the slower vehicle, reducing both average operating speed and highway capacity.

The term "Critical Length of Grade" is indicated as the maximum length of a specific grade upon which a loaded truck, with a weight to horsepower ratio of 300, can operate without a reduction in speed of 10 mph. The data contained in 2001 AASHTO Exhibit 3-63 shows the speed reduction resulting from various combinations of grade and length of grade.

On highways with moderate to heavy traffic volumes, where critical lengths of grade are exceeded, consideration shall be given to providing a climbing lane. By itself, this analysis is not a warrant for climbing lanes, but an indication that further study may be required. Some factors such as percentage of passing sight distance, percentage of heavy trucks, desired level of services, service volume, cost, etc., are taken into consideration and capacity analysis performed.

Summary. Climbing lanes offer an inexpensive means of overcoming capacity losses and improve operation where congestion on grades is caused by slow trucks in combination with high traffic volumes. The addition of climbing lanes on some existing highways could defer reconstruction for many years. On new designs, climbing lanes could make a two-lane facility adequate, whereas a more costly multilane might be necessary without them. Climbing lanes are warranted where the critical length of grade is exceeded and the level of service obtainable is one level poorer than that desired for the facility.

Climbing Lane Criteria. Climbing lanes shall be as wide as the through lanes, preferably 12 feet. The cross slope shall be the extension of the main line cross slope for alignments on tangent and for the low side of superelevated roadways. The maximum superelevation of climbing lanes on the high side of superelevated curves shall be limited to 4.0%. A usable shoulder width of 4 feet is acceptable adjacent to climbing lanes.

A tapered section, desirably 25:1, but at least 150 feet long shall precede the beginning of the climbing lane. Ideally, the climbing lane shall extend beyond the crest of the vertical curves to a point where the truck could attain a speed that is the mainline speed. In some instances, this may not be practical; therefore, a practical point to end the climbing lane is where the truck can return to the normal lane without undue hazard, that is, where sight distance becomes adequate to permit passing with safety. In addition, a desirable taper based on a ratio of 50:1 shall be added, or a minimum taper length of 200 feet.

Emergency Escape Ramps. Emergency Escape Ramps shall be considered in Allegany, Garrett, Frederick and Washington counties on new expressways and arterial highways that utilize a sustained grade of 4.0% or steeper and a length of 1/2 mile or more. (Refer to 2001 AASHTO, page 263, for various types of ramps).

Vertical Curve Design. Vertical curves shall result in a design that is safe, comfortable, adequate for drainage and smooth in appearance.

The major control for safe operation on vertical curves is adequate stopping sight distance. In all normal instances on crest vertical design, the designer shall use the criteria based on the height of eye of 3.5 feet and a height of object of 6 inches. The crest of the curve shall not obstruct the line of sight. In areas of complex and multiple decision points, additional sight distance shall be provided (Refer to 2001 AASHTO, Elements of Design, pages 115-117).

Nighttime driving conditions govern sag vertical curves. For safety, a sag vertical curve shall be long enough that the illuminated distance (headlight beam) is nearly the same as the stopping sight distances.

For main line vertical alignments the following vertical curve lengths shall be considered minimum

CREST	1000 feet (MINIMUM)
SAG	800 feet (MINIMUM)

For flat gradients where sight distance is not a factor and the algebraic difference in grades (A) is small, the minimum length of curve for mainline roadways shall be no less than the design speed in meters. Computed vertical curves may not be necessary and are considered the designer's option when the algebraic difference in grades (A) is 0.3% or less for highways using design speed of 50 mph or greater and 0.5% or less for highways using a design speed less than 50 mph.

The length of vertical curve divided by the algebraic difference (L/A) represents the horizontal distance required to effect a 1 percent change in gradient along the curve. This quotient is termed K and is useful for determining minimum lengths of curves as well as high and low points on vertical curves. The horizontal distance from the point of vertical curve (PVC) to the high point of crest and the low point of sag vertical equals K times the approach gradient.

Drainage affects the design of vertical curves. On the pavement surface of curbed sections, no difficulty with drainage is experienced if the curve is sharp enough so that a minimum grade of 0.3% is reached at a point about 50 feet from the crest (or sump). Special attention to drainage shall be exercised where a K-value in excess of 167 is used.

Elevation of the Profile Grade. In the case of Special Project type of improvements and most urban areas, there is little opportunity for large variation in the profile gradeline elevation. The existing facility and/or adjacent roadside development usually control these elevations.

However, for new construction or major reconstruction in rural areas, particular attention shall be given to the elevation of the proposed grades. This is particularly true in relatively low areas with level terrain. Structural problems can occur where the pavement bases or upper portions of the embankment become saturated with water or high water encroaches on the roadway shoulders and surface.

Generally, the finished grade elevation shall be above the surrounding terrain in these cases and preferably higher in the case of a relatively high normal water table. Where there is evidence of occasional standing water in adjacent ditches or fields, the gradeline shall be high enough to assure drainage of the pavement base course at high water level. This can be of particular concern in lower Eastern Shore counties. Generally, when setting the vertical alignment in these counties, embankment areas shall not be less than 3 feet in depth. This will eliminate the need to grub the embankment areas in accordance with Section 101.00 of the Specifications. Allowing the root mat to remain in place will assist in maintaining the stability of the existing ground.

Entrance Profiles. Special attention shall be given to driveways and entrances, particularly on urban construction. Driveway/Entrances are in effect at-grade intersections. Sight distance is a significant design control (generally associated with rural highways) and driveways should be avoided where sight distance is not sufficient. The number of accidents is disproportionately higher at driveway terminals than at other intersections; therefore, their design and location merit considerations. Vertical breaks shall be kept as flat as possible to provide clearance for the under carriage or bumpers of vehicles entering/exiting these points of access. The designer shall be familiar with the Administration's publication "Rules and Regulations for Commercial, Subdivision, Industrial, Residential - Entrances to State Highways." In addition, additional data for grade tie-ins for urban highways is illustrated on Standard No.'s MD 630.01, 630.02 and 630.11 and Figure VA-2 of these procedures.

TABLE VA- 1 MAXIMUM MAINLINE GRADES FOR MARYLAND HIGHWAYS

TYPE OF TERRAIN	**DESIGN SPEED IN MPH**			
	40	**50**	**60**	**70**
LEVEL	5%	4%	3%	3%
ROLLING	6%	5%	4%	4%
MOUNTAINOUS	8%	6%	6%	5%

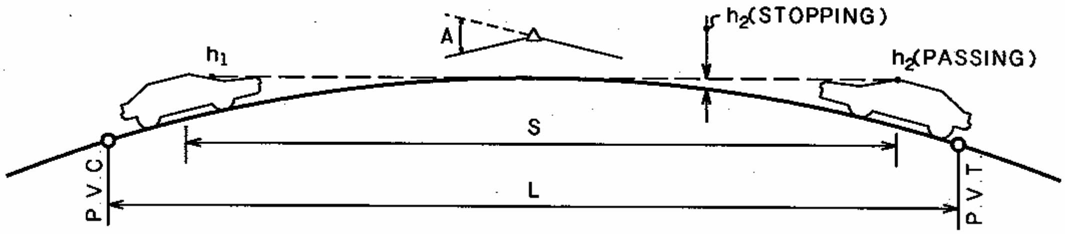
1. Vertical alignment should be designed in conjunction with the horizontal alignment.
2. Maximum grades should be used as infrequently as possible. Use of flatter grades is encouraged. In URBAN areas where development precludes the use of flatter grades, for short grades less than 500 ft and for one-way downgrades (except in mountainous terrain) the maximum gradient may be 1.0% steeper.
3. The type of terrain pertains to the general character of the specific route corridor. Routes in valleys of mountainous areas that have all the characteristics of roads traversing level or rolling terrain should be classified as rolling or level as the case may be.
4. For local roads and streets, refer to applicable County standards.

TABLE VA-2 SIGHT DISTANCE CRITERIA

DESIGN SPEED IN MPH	30	40	50	60	70
STOPPING SIGHT DISTANCE (feet)	200	325	475	650	850
CREST K VALUE	40	100	215	400	680
SAG K VALUE	40	70	110	160	220
PASSING SIGHT DISTANCE (feet)	1100	1500	1800	2100	2500
CREST K VALUE	440	610	1070	1600	2250
DECISION SIGHT DISTANCE (feet)	625	825	1025	1300	1625

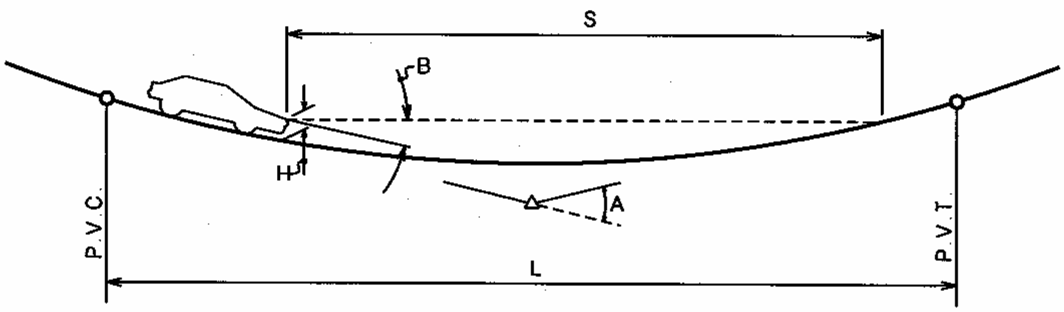
In using this table, the designer can check his plan to compare all curves using the design K value (L=KA).

NOTE: Refer to HORIZONTAL ALIGNMENT - DESIGN CONTROLS, page 4 of 5, for additional information.



CREST

FORMULA : WHEN $S<L$; $L = AS^2 \div 100(\sqrt{2h_1} + \sqrt{2h_2})^2$



SAG

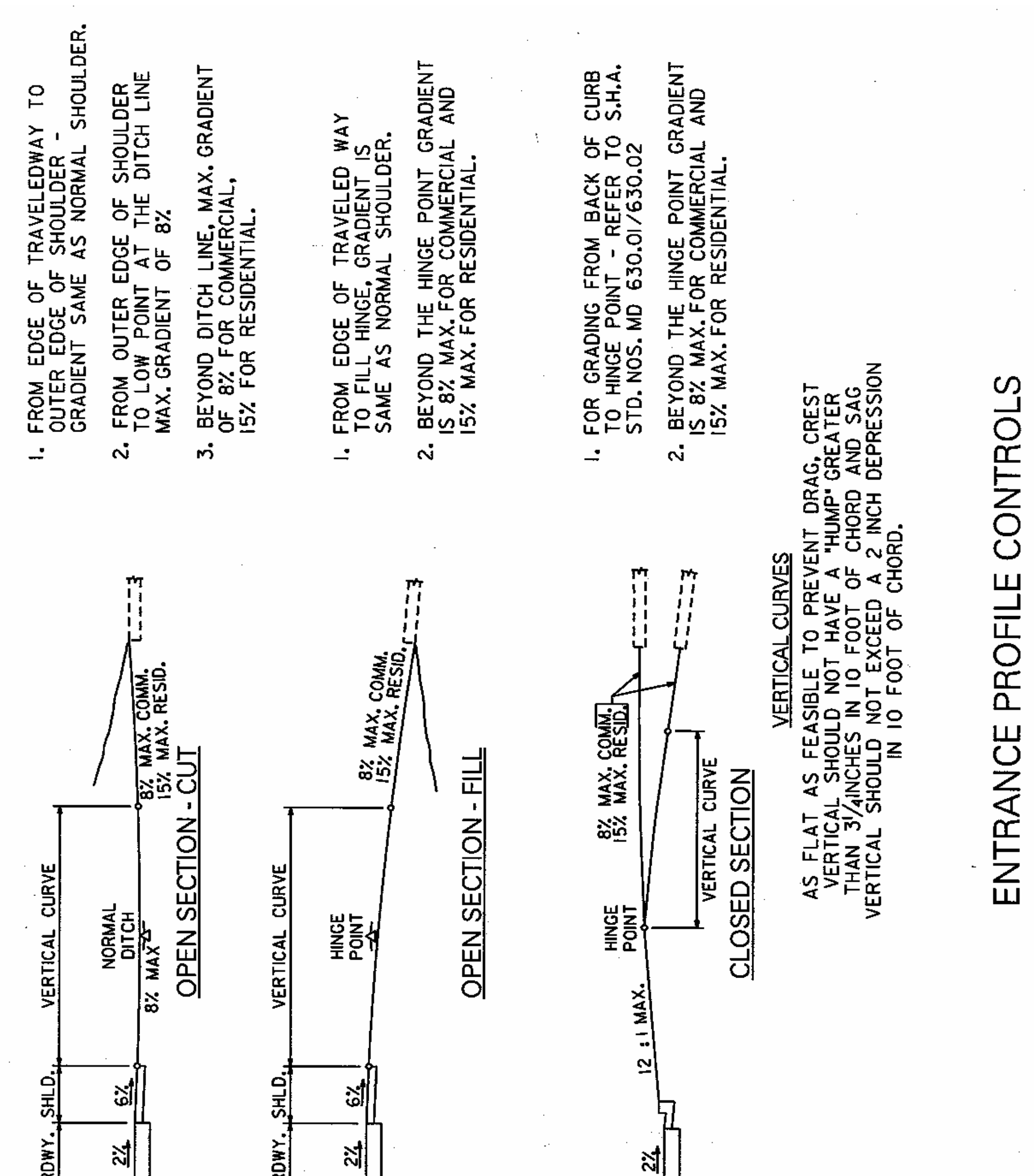
FORMULA : WHEN $S<L$; $L = AS^2 \div (400 + 3.5\ S)$

L = LENGTH OF VERTICAL CURVE (FEET)
A = ALGEBRAIC DIFFERENCE IN GRADES (%)
S = SIGHT DISTANCE (FEET)
K = VERTICAL CURVE (L/A)
H = HEADLIGHT HEIGHT (2 FEET)
B = UPWARD DIVERGENCE OF LIGHT BEAM (1 DEGREE)

	PREFERRED	ACCEPTABLE
h_1	3.0'	3.5'
h_2 (STOPPING)	0.33'	0.5'
h_2 (PASSING)	4.0'	4.25'

VERTICAL CURVE - SIGHT DISTANCE SKETCH

FIGURE VA-1



1. FROM EDGE OF TRAVELEDWAY TO OUTER EDGE OF SHOULDER - GRADIENT SAME AS NORMAL SHOULDER.
2. FROM OUTER EDGE OF SHOULDER TO LOW POINT AT THE DITCH LINE MAX. GRADIENT OF 8%
3. BEYOND DITCH LINE, MAX. GRADIENT OF 8% FOR COMMERCIAL, 15% FOR RESIDENTIAL.
RDWY. SHLD. VERTICAL CURVE
2% 6%
NORMAL DITCH
8% MAX
8% MAX. COMM.
15% MAX. RESID.
OPEN SECTION - CUT
1. FROM EDGE OF TRAVELED WAY TO FILL HINGE, GRADIENT IS SAME AS NORMAL SHOULDER.
2. BEYOND THE HINGE POINT GRADIENT IS 8% MAX. FOR COMMERCIAL AND 15% MAX. FOR RESIDENTIAL.
RDWY. SHLD. VERTICAL CURVE
2% 6%
HINGE POINT
8% MAX. COMM.
15% MAX. RESID.
OPEN SECTION - FILL
1. FOR GRADING FROM BACK OF CURB TO HINGE POINT - REFER TO S.H.A. STD. NOS. MD 630.01/630.02
2. BEYOND THE HINGE POINT GRADIENT IS 8% MAX. FOR COMMERCIAL AND 15% MAX. FOR RESIDENTIAL.
2%
12 : 1 MAX.
HINGE POINT
8% MAX. COMM.
15% MAX. RESID.
VERTICAL CURVE
CLOSED SECTION
VERTICAL CURVES
AS FLAT AS FEASIBLE TO PREVENT DRAG, CREST VERTICAL SHOULD NOT HAVE A "HUMP" GREATER THAN 3 1/4 INCHES IN 10 FOOT OF CHORD AND SAG VERTICAL SHOULD NOT EXCEED A 2 INCH DEPRESSION IN 10 FOOT OF CHORD.
ENTRANCE PROFILE CONTROLS

FIGURE VA-2